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A1

Southwest Energy Efficiency Project

Saving Money and Reducing Pollution through Energy Conservation

SWEEP

Policies and Programs for Saving Energy through Enhanced Duct Systems

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Prepared for

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Building America Program

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Preface

This report on duct systems in Southwestern homes is one in a series of policy briefs prepared by the Southwest Energy Efficiency Project (SWEEP) in support of the U.S. Department of Energy's Building America Program. Its intended audience includes energy program policy makers, planners, and analysts. It includes information on energy and economic analyses associated with various levels of the penetration of energy-efficient distribution technology and associated policy options. Feedback from all readers on the form and content of this report is welcome. A companion report, "Duct Systems in Southwestern Homes: Problems and Opportunities," is aimed at builders and design professionals interested in employing technologies that will reduce energy costs in both new and existing housing stock. Both reports are available for downloading at www.swenergy.org.

Introduction

The U.S. Department of Energy (DOE) has long recognized that distribution systems associated with forced air heating and cooling can cause substantial energy waste—as well as adversely affect the safety of homes and the health of those who live in them. Over the years, DOE has supported a range of research and development activities with national labs, ASHRAE, the Air Conditioning Contractors of America (ACCA), and others to study the problem and help solve it. Industry has responded in helpful ways, from developing techniques and tools for assessing duct performance to techniques and tools to improve it. For example, ACCA, which publishes Manual D on residential duct systems, has also produced "Residential Duct Diagnostics and Repair," an excellent text written by John Andrews of Brookhaven National Laboratory. This document announces at the outset that "typical duct systems lose 25 to 40 percent of the heating or cooling energy put out by the central furnace, heat pump, or air conditioner...some types of systems (such as attic ducts in hot, humid climates) often lose more" (Andrews 2003).

The Energy Performance of Buildings Group of the Lawrence Berkeley National Laboratory paints the national duct picture even more poignantly: "Each year, U.S. residential duct leakage costs consumers $5 billion. This energy loss is equivalent to the annual oil production from the Arctic National Wildlife Refuge [or] the annual energy consumption of 13 million cars. The carbon dioxide uptake of 7 billion trees is needed to offset the global warming impacts of this energy waste" (LBNL 2003).

Building homes with better distribution systems in them as well as retrofitting existing duct systems can yield substantial savings of fuels used for heating and cooling. Summarizing 19 studies of both new and existing homes, all but one of which reports on homes in moderate-to-hot climates, ACEEE reported energy savings potentials from improving duct performance averaged 17% (Neme *et al*, 1999). Further, cooling energy savings achieved by highly-efficient duct systems are inevitably accompanied by peak savings since hot summer afternoons are the times air conditioning systems run the most and utilities experience peak loads that are costly to meet. Accordingly, a number of utilities have conducted (or co-sponsored) efficiency programs that have duct repair as a central feature. Most of these have been in regions outside of the Southwest, most notable in the Southeast and the West.

Through DOE's weatherization assistance program, which provides energy retrofit services to several hundred thousand lower income-occupied homes per year, a good deal of duct sealing is being accomplished all over the country. In fact, weatherization is the only large-scale existing residential conservation program in the Southwest that routinely includes retrofits of distribution systems, and several utilities in the Southwest co-sponsor local weatherization agencies.

As regards duct-efficiency programs for new homes, Tucson Electric has a program that includes duct sealing as a key measure (among others) leading to efficient new homes whose energy bills are guaranteed not to exceed a specified level (Kinney 2003). In addition, a broad-based effort aimed at improving the overall performance of new homes, bringing them above ENERGY STAR® performance levels, was launched by Utah Power in the Spring of 2005. Raising duct efficiency is a major component of the program.

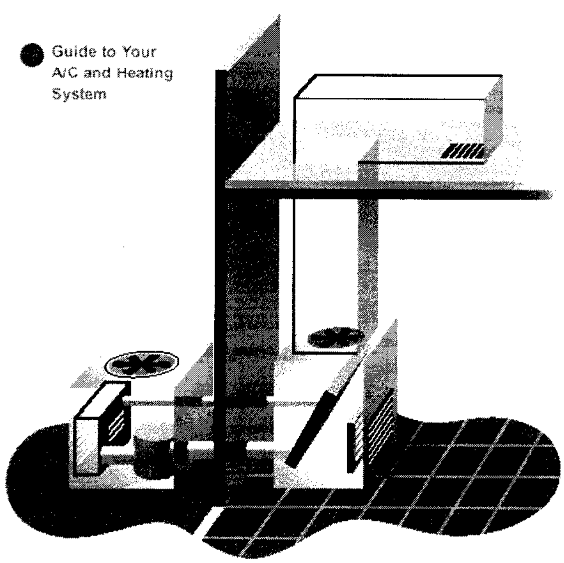
Both the Building America and ENERGY STAR programs are active in promoting more energy efficient distribution systems, both through stimulating understanding on the part of builders and HVAC contractors and through testing of results. Additionally, the International Energy Conservation Code (IECC) includes provisions that specify insulation levels and urge tightness of ducts, but do not contain mandatory duct sealing requirements.

This report describes a handful of duct efficiency programs that are of relevance to the southwest region as well as a review of treatment of ducts in modern building codes. It discusses policy and program options that are likely to contribute to improving distribution systems—and overall energy performance, health and safety—in new and retrofit homes.

Although many new homes are being built to higher efficiency standards and include more attention to duct sealing and insulating than in the past, there is plenty of room for improvement in both new homes and (in particular) existing dwellings. Stronger codes can hasten the advent of better new homes. In addition, well-designed DSM and related programs that include duct efficiency as a key feature can achieve cost effective energy and demand savings in new and existing homes throughout the Southwest. Recommendations begin on page 19.

Duct Retrofit Programs
Florida Power and Light

Prominently displayed on the home page of the Florida Power and Light's web site is the first bullet item under Featured Services: "Duct System Test: Repairing ducts is often easy and inexpensive." Clicking on Duct System Test yields a page of explanation on FPL's duct repair program and an animated graphic (Figure 1) explaining how HVAC systems typically work (www.fpl.com/home/energy_advisor/cooling_heating/contents/ducttest.shtml).



Source: FPL

Figure 1. Graphic on FPL web site illustrating HVAC configurations in typical single-family housing stock. Frequently the air handler is in unconditioned garages.

The message on the site states that two-thirds of all homes have leaky ducts that go undetected, but with FPL's help, they can be repaired inexpensively with energy savings and improvement in indoor air quality.

Customers are invited to schedule a duct inspection at the nominal cost of $30 for the first air handler and $15 for each of the others. A representative of the utility produces a report on the leakiness of the ducts, a specification for repair work, and a list of qualified contractors. If the customer elects to have the work done, FPL writes down the cost of the work by providing incentives of up to $154 for single family detached homes with central A/C, $57 for single family attached homes, and $65 for manufactured and mobile homes.

Table 1 shows program activity, savings, and cost information on the FPL program for the past five years.

Table 1. FPL Duct System and Repair Performance for the Period of 2000–2004

Year	2000	2001	2002	2003	2004	5 yr Totals
Number of Installs	11,446	23,198	35,206	22,920	17,949	110,719
Summer Peak Savings (MW)	2.651	3.826	5.348	3.607	2.85	18.282
Winter Peak Savings (MW)	2.641	3.826	5.348	3.607	2.85	18.272
Energy Saved (MWh)	6,036	8,728	12,200	7,430	5,820	40,214
Energy Saved/Install (kWh/yr)	527	376	347	324	324	363
Peak Saved/Install (kW)	0.232	0.165	0.152	0.157	0.159	0.165
Total Costs to FPL ($000)	2,996	2,911	3,365	2,622	2,018	13,912
FPL Cost/Install ($)	$262	$125	$96	$114	$112	$126

Source: Tom Ruthig, Florida Power and Light

Progress Energy

Progress Energy is an investor-owned electric utility that serves a 20,000 square mile service territory in Central Florida that includes the City of Orlando. Because the service territory contains a number of winter residences of people who live in northern states for the rest of the year, it is a winter-peaking utility. Progress Energy has been running a duct sealing program since the early 1990s.

A walk-through energy audit, a free service of Progress Energy, is a necessary condition for qualifying for the duct program. The auditor performs a visual check of the distribution system and recommends the duct program (along with other energy-saving measures) if appropriate. If the customer elects to have their ducts tested, Progress Energy pays for half of the cost of a duct test or $30, whichever is less. If there are multiple HVAC systems at the same address, tests for systems after the first are reimbursed at $20 each. In practice, contractors provide testing services for $60 if there is one HVAC system and $100 if there are two, so effectively Progress Energy writes down the cost of the testing service by half.

The result of the duct test is a sketch of the distribution system plus an indication of disconnects, leakage areas, and overall leakage amounts—along with a proposal to do the recommended work. This usually involves securing flex ducts at each end of their runs with mastic and tape, as well as accomplishing other air sealing at the air handler, and the like. About 70% of customers elect to have the duct repair work done, and Progress Energy pays for half of the cost up to a maximum of $100 per unit for homes with ducted electric heat (whether electric resistance or heat pump). If customers do not use a ducted heating system (but have central A/C, for example), the incentive payment is lowered to 25 percent of the repair cost up to a maximum of $50 per job.

The point of this incentive structure from Progress Energy's perspective is that the program results in demand savings that are only valuable in the heating season. The program's manager, Guy Fish, estimates that on average, a residential duct repair job results in 1 kW of demand savings and about 585 kWh per year of energy savings (Fish 2005).

The program served almost 4,000 customers in 2003, but dropped to 2,144 in 2004 for reasons that are unclear. Participation is expected to be well over 3000 in 2005. Progress Energy uses from 8 to 10 contractors, all of whom have technicians on their staffs who have been trained by the utility and are certified to supply services. In the beginning, technicians were trained by John Tooley and others at the Florida Solar Energy Center, but FSEC no longer offers the service. Instead, the company conducts a four-day training program similar to the FSEC training program which produces certified duct repair technicians. Contractors range in size from one-person outfits which specialize in the Progress Energy duct repair program to large HVAC businesses with staffs of 50 or more.

Tampa Electric Company (TECO)

TECO is an investor-owned utility that serves the greater Tampa area; the company has about 545,000 residential customers. Historically, TECO has been a winter-peaking utility, and a substantial majority of its customers use heat pumps. According to Tim Richardson of TECO's regulatory department, the utility is about to become a summer-peaking utility (Richardson 2005). Duct repair work helps to shave both summer and winter peaks and provides customers with energy savings benefits that pays back from their perspective in less than a year.

Tampa Electric's Ductwork Program for existing homes has been in operation since 1992, with mid-course corrections taken about every five years in response to evaluations of performance. John Tooley, a Florida native and pioneer in identifying problems and proposing solutions associated with distribution systems, was influential in getting duct repair programs underway in all three electric utilities in the state, including TECO's.

About half of the air handlers in TECO's service territory are located in garages, typically on supports that elevate them above the floor by about two feet. These supports contain (or constitute a part of) the return plenum. These tend to be leaky, but the leakage areas are routinely visible to the attentive technician and can be quickly repaired using ductboard, special mastics and fiberglass mesh if needed. Most other homes have air handlers in the attic. Leakage areas associated with the plenums, trunks, and ducts in the attic are also visible to the trained technician and may be readily repaired or strengthened. (Flex ducts in attics are the routine in Florida.) TECO provides customers with a list of participating contractors to both repair duct leaks and to strengthen the duct joints that are not yet very leaky, as a preventative measure.

The deal at the outset of the program for customers was to co-pay a portion of the job; TECO paid $100 if the repair work was not major, $175 if it was.

Evaluations revealed several problems with this arrangement. First, the demand for the program outstripped the supply, particularly during summer months when the HVAC contractors participating in the program were swamped with their regular business. So instead of having ducts repaired in the midst of the summer when the need was at a maximum, homeowners would have to cope with "please call us again in September." Second, the contractors tended to overcharge for their services. Accordingly, in the next revision of the program, blower doors were introduced, assigned contractors were given more training, and the focus was on dealing directly with leaks instead of preventative joint strengthening. Further, benchmarks on costs were established, which contributed to much better cost effectiveness.

The program has recently been fine tuned again. Since the contractors have now been with the program for a long time, there is no longer a need to use blower doors to identify leakage areas. On the other hand, they have gone back to doing reinforcements. Quality is good, but costs are in control. Customers are required to spend $79, while the utility spends about $168 on typical jobs. Contractors can make enough money ($247) to make the service worthwhile in part because they sometimes pick up additional HVAC work.

Over the 13 years of running one version or another of the program, about 43,000 retrofit duct jobs have been accomplished, about 8 percent of TECO's residential customer base. Several years ago, the program peaked at 5,200 jobs per year, and is now averaging about 3,000. Customers can sign up online for the Ductwork Program as well as for a free Home Energy Audit (www.tampaelectric.com/TEESHMDuctwork.cfm).

Both peak savings and energy savings flow from the program. In an evaluation of the 2004 program, TECO estimates that on average, a Ductwork Program job results in 0.45 kW peak reduction in summer and 0.39 kW peak reduction in winter, with annual customer electricity savings of 988 kWh per year. Residential customers pay 8.7 cents per kWh plus local franchise fees and taxes, so their energy bill savings make up for their $79 cost for the service in well less than a year.

SMUD

The Sacramento Municipal Utility District (SMUD) is a large, municipally-owned utility in central California. It supplies a 900 square mile service territory whose population is 1.2 million and has 554,000 customers. The utility had a peak demand of 2,809 megawatts on a July day in 2003.

SMUD offers rebates for various energy-efficiency measures (see www.smud.org/residential/saving/rebate.html) and actively promotes a residential duct-improvement program the utility initiated in 1999 (Kallett *et al*, 2000). It writes down the $75 cost of a detailed duct audit by $50 and supplies an additional incentive of $300 toward defraying the cost of duct sealing and insulating if the audit reveals losses to the outside of the conditioned envelope of over 15% of the HVAC system's rated air flow. SMUD also provides financing services at reasonable rates if the customer desires.

The audit itself involves measuring the pressure differences between the conditioned envelope and outside with the air handler off, with it running on high, and with it running on high with about 80 percent of the return air ducts blocked off. In addition, the technician tests flow and temperatures at each supply duct as well as return air flows under ordinary operating conditions. Finally, the combustion air zone is examined under worse-case conditions for possible backdrafting and the presence of carbon monoxide. This information is the basis of a five page audit report prepared on site. If tests reveal it would be cost effective to undertake duct remediation, the customer is given a proposal for duct remediation (as well as for more extensive work on the HVAC system if appropriate.) In practice, roughly 75% of homes examined require retrofit work and closure rates are running around 25% (Laity 2005).

In the early days of the program (after the first 593 aerosol-sealing jobs), many customers had additional work completed, ranging from electro-static filters (13%), thermostats (7%), and duct cleaning (32%) to entire new HVAC systems (14%). (Kallett *et al*, 2000)

If the customer elects to have the work done, it can be accomplished by one of five contractors currently approved by SMUD, all of whom are franchisees of the Aeroseal Company (www.Aeroseal.com; technical details are also available in "Duct Systems in Southwestern Homes: Problems and Opportunities" at www.swenergy.org). Contractors approved for listing by SMUD must meet three criteria: they must agree to install equipment and materials to SMUD's specifications, be licensed contractors in California, and maintain current insurance coverage. Although the utility does not endorse specific contractors, it actively promotes the program both through its web site and via bill stuffers. A sample of the program brochure may be downloaded from http://www.smud.org/residential/saving/faqs_pdfs/Aeroseal_factsheet.pdf.

Duct sealing is accomplished by the Aeroseal technique, which blows small adhesive particles through pressurized duct work. As the particles are drawn to exit leakage areas, they tend to stick at the openings, thus contributing to filling in the hole. The process is controlled and monitored by a system of pressure gauges and a laptop computer, which plots progress in sealing and produces a detailed report of the degree of air sealing accomplished by the process on both supply and return ducts. A copy of this report is used to document accomplishments and serves to establish proof that the customer is eligible for a rebate from SMUD.

At the outset of the program, SMUD solicited contractors, selected four, wrote down the cost of the franchise fee of $20,000 by half, co-sponsored training, heavily promoted the program, and paid $400 rebates to customers having sealing work accomplished. Launched in mid 1999, customer response was immediate and substantial (Figure 3), and soon three other contractors joined the SMUD program. Several years later, the rebate amount was dropped to $200. This roughly coincided with the calamity of 9/11 and associated economic downturn as well as with

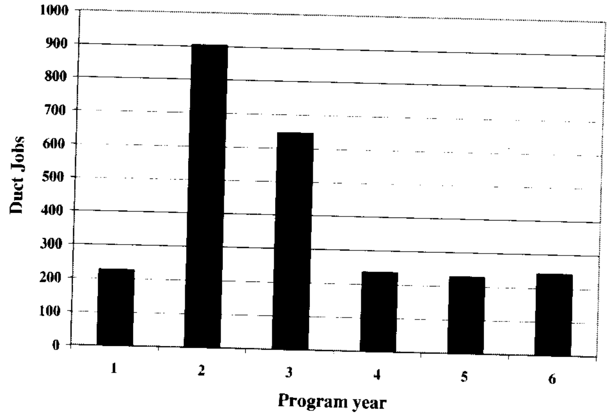


Figure 3. Jobs completed by program year (Source: SMUD 2005)

higher costs of supplying sealing services, from about $900 to an average of $1200. As a consequence, interest in the program flagged and several contractors dropped out. Recently, SMUD raised the rebate amount to $300 and interest is building again.

There are currently five contractors, two of whom have been in the program since its inception.

SMUD works closely with the contractors to try to match demand for the program to the contractors' ability to meet it. At the outset of the program, an article in the local newspaper in conjunction with a bill stuffer caused a backlog of many months duration. Now, in addition to the occasional bill insert and ongoing information on SMUD's web site, letters describing the program are prepared for residential customers with particularly high bills. The timing and magnitude of these mailings are adjusted in the light of contractors' feedback on their current backlogs (Kallett 2005).

SMUD estimates that annual electric-energy savings per sealing job averages 690 kWh (about 20 percent). This value is a weighted average based on half of the participating homes having electric heat (typically heat pumps), the other half having gas heat, and all homes having central air conditioning. Summer peak demand reduction is estimated at 0.5 kW per job. SMUD has an ascending block rate pricing structure that is "designed to encourage conservation" in the words of its web page on rates. Further, electricity rates are higher in the summer than in the winter (Table 2).

Table 2. SMUD Residential Rates

Ranges and Rates	Tier 1	Tier 2	Tier 3
Summer tiers (kWh range)	0 - 700	701 – 1,000	1,001 +
Summer rate (cents per kWh)	8.66	15.10	16.83
Winter tiers all electric (kWh range)	0 – 1,120	1,121 – 1,400	1,401 +
Winter tiers gas heated (kWh range)	0 - 620	621 - 825	825 +
Winter rate (cents per kWh)	7.98	14.13	15.37

Summer electricity rates are 16.83 cents per kWh for customers who consume over 1,000 kWh per month. In some cases, improvements to ducts can lower summer monthly electricity consumption to the point where a previously high consuming customer can be billed at a lower rate, which amounts to a savings of 1.73 cents per kWh. If customers manage to drop to 700 kWh per month, rate savings for dropping from Tier 2 to Tier 1 are 6.44 cents per kWh. From the customer's point of view, when a $1000 duct air sealing job is subsidized by a $300 rebate from SMUD, paybacks for homes with heat pumps or conventional A/C plus gas furnaces average about 7 years.

Mobile Home Duct Programs

Energy Trust of Oregon

In 1999, the Oregon legislature passed an electric industry restructuring bill that required the two investor-owned electric utilities in the State, Portland General Electric and Pacific Power, to collect a three percent public benefit charge from their customers and use it to fund energy efficiency and renewable energy projects. In March of 2002, the Oregon Pubic Utility Commission created the Energy Trust of Oregon as an independent, nonprofit organization to administer the efficiency and renewable work. In addition to administering the efficiency programs of the electric utilities, in 2003 the Energy Trust began running the energy efficiency programs of the State's gas utility, NW Natural (see www.energytrust.org).

One of the first efficiency efforts undertaken by Energy Trust was a duct sealing program aimed at mobile homes. A 1,000 home pilot was not only successful, but also the winner of an honorable mention program award from the American Council for an Energy Efficient Economy, "America's Best: Profiles of America's Leading Energy Efficiency Programs" (York and Kushler, 2003). Since then, the program has become fully operational and over 5,000 homes have been retrofitted since the program's inception. As of the spring of 2005, participation is at about 125 homes per month.

The program is a free service to residents of mobile homes who have electric furnaces, which is the case for the large majority of manufactured homes in the state. Since there is no marketing of services needed between testing and treating, the two are combined. Somewhere between 85% and 90% of the homes tested can be cost effectively retrofitted (Manclark 2005).

As described in the technical companion piece to this document, the testing procedure involves a pair of calibrated fans, a duct blaster and a blower door. Skilled crew people can accomplish the diagnostic procedure in 20 minutes. If the testing reveals that a home can be cost effectively retrofitted, work is begun right away. It almost always involves working with both metal flashing and mastic at the interface between the furnace and the main supply plenum and at the risers.

Post-testing is accomplished on all jobs. Results are used to track accomplishments for purposes of program evaluation—and to provide contractors with data to support bragging rights, an important element in program quality control (equaled only by training). Most training is delivered in the field, rather than in classrooms with Power Point presentations and "how to do it" manuals. "We work with crews as imbedded duct trainers for at least a week or two," explains Bruce Manclark. "By then they've seen a good sample of most of what can go wrong with mobile home ducts and they've learned enough to be able to solve new problems on their own." In all events, he and his colleagues are available for providing technical assistance when needed.

The work is accomplished by one- or two-person crews and takes from 2.5 to 3.5 hours. The Energy Trust pays contractors $50 for cases in which the ducts are too tight to merit sealing and $350 for "non-complex" sealing jobs. Once in a while, whole sections of ducts have been crushed or even destroyed and must be replaced. Under these circumstances, the Energy Trust pays for "complex" work at a rate that is negotiated with the contractor.

At its peak, there were a dozen contractors involved in the Energy Trust duct program, but the number of active contractors is presently about six. Since the Energy Trust receives its funding from the major investor-owned utilities operating in the state, the service is limited to their customers.

At the outset of the program, estimates of savings were 1,200 kWh/year for heating; there is very little compressor-based cooling in Oregon. In the light of recent evaluations, this figure has been revised to 800 kWh/year, a number that represents about a 10% to 15% savings of annual heating energy use. Demand savings are estimated at 0.31 kW (Ferington 2005). At the average residential electricity price of $0.07 per kWh, the $350 sealing cost is paid back in 6.25 years through energy bill savings.

Eugene Water & Electric Board

A similar program is being conducted by the Eugene Water & Electric Board (EWEB), a municipal utility that serves 82,300 customers (73,600 residential) in a 472 square mile service territory in the area around Eugene, Oregon.

When the "Comfort Seal" program (Figure 2) was started in 1996, it was decided to concentrate on older mobile homes that were known to be particularly wasteful, in large part due to leakage between the furnace and the supply plenum. A free service to mobile home owners, it costs EWEB about $350 per home. As part of outreach efforts, representatives of EWEB would attend pot luck dinners and make presentations about the program, as well as leaflet entire mobile home parks with door hangers. As a result, in the heyday of the program, 600 to 700 mobile homes per year were served.

Source: EWEB

Figure 2. Comfort Seal

As of the spring of 2005, Bob Lorenzen, EWEB's demand-side management programs manager, estimates that about 2,100 of the 3,000 mobile homes in EWEB's service area have already been served, and many of the rest of the homes are newer models whose envelopes and ducts are both quite tight (Lorenzen 2005). As a result, participation has dropped to around 50 per year. Further, a good deal of current work is concentrated on the repair of crossover ducts on double-wide units.

In spite of Eugene's mild climate (4700 heating degree days with a 99.6% winter design dry bulb temperature of 21°F), older mobile homes with electric resistance heaters use 15,000 to 20,000 kWh per year for heating, although substantially less if they have heat pumps. Savings due to duct sealing are about 10%, 1500 to 1700 kWh per year for units with electric resistance heaters and about 1000 kWh per year for those with heat pumps. Bob Lorenzen attributes this level of savings to two factors: quite wasteful units with leaky ducts (savings follows waste) and the use of a single contractor who has high standards of performance (Delta T).

Note that in areas where air conditioning is prevalent with mobile homes, annual energy and demand savings from air sealing ducts are likely to be substantially greater.

Hard-to-Reach Mobile Home Program in California

Three major utilities in California—Pacific Gas and Electric, Southern California Edison, and Southern California Gas—co-sponsored an energy retrofit program targeted at "hard to reach" mobile homes in their service territories. The program retrofitted 12,000 mobile homes over a two year period from 2002 and 2003. It was conducted by the American Synergy Corporation and CAL-UCONS, and evaluated by Robert Mowris & Associates and Stellar Processes (Blankenship *et al*, 2004).

Instead of dealing only with ducts, the program installed a total of 82,808 measures in the 12,000 mobile homes. Although the most important measure, both in cost and resulting savings, was duct sealing—accomplished on the 8,370 homes (70%) that needed it—a number of other measures were also undertaken as needed. Almost 54,000 compact fluorescent lights (CFLs) were installed (an average of 4.5 per household) and 3,188 (27%) air conditioner tune ups were accomplished. Over 1,100 programmable thermostats were installed, as were low-flow showerheads (64% of homes) and faucet aerators (69%). Three other measures—envelope air sealing, water heater tank insulation, and hot water pipe insulation—were also installed on a handful of homes, well less than one percent for each measure.

In addition to physical measures, participants received energy education consisting of talking to consumers about energy efficiency in their homes as well being given written material. Participants were given two documents: a guide to smarter home energy use in pamphlet form entitled "Energy Education Tips," and a "Test in and Test out Certificate" indicating what was done on the home and measurements of energy-related parameters before and after retrofit. A copy of this certificate was also useful in the monitoring and evaluation process.

The overall program was found to be cost effective according to the Total Resource Cost (CRC) test, having a benefit-to-cost-ratio of 1.52 at an average cost per household served of $315. Savings averaged 640 kWh per year with a peak demand savings of 0.31 kW plus natural gas savings of 56 therms per year. Contractors were paid by the measure (e.g., $250 for duct testing and sealing, $125 for an A/C tune up, and $90 for installing of a digital set-back thermostat), so it is possible to estimate by-measure savings achieved versus costs. For ducts, savings averaged 347 kWh/year and 0.21kW of summer peak demand, with a gas savings of 70 therms for the 70% of homes for which duct retrofit work was accomplished.

A participant satisfaction survey consisting of 8 questions was administered to a randomly-selected group of 300 customers. Overwhelmingly positive results were obtained (e.g., to the question "how would you rate the overall service you received on a scale of 1 to 100," the response averaged 98).

Evaluation of the duct sealing portion of the program resulted in findings likely to be useful to future mobile home retrofit programs. The "deal" with the contractors who did the work was that they had to achieve no more than 60 cfm of duct leakage at 25 Pa per ton of A/C installed or 15% leakage reduction, whichever was less, to be paid the agreed-upon $250. Although the program averaged 18% reduction in duct leakage, in practice, many contractors took meeting these thresholds as constituting an adequate job even if prospects for accomplishing further sealing were apparent. Accordingly, many opportunities were lost. For example, the furnace room itself is frequently leaky to the outside via the furnace flue pipe and other holes. Since return air is typically drawn through a grill in the door of the furnace room that's covered by a crude—and frequently cruddy—filter, a good deal of return air can be drawn through holes in the furnace room from the outside, thereby lowering the system efficiency of the HVAC system. The program evaluators found that such holes were often missed during the sealing process. They also found that contractors rarely did adequate air sealing work on systems that have supply ducts in ceilings and returns below the floor (Mowris 2005).

The solution suggested by the evaluation team is to provide duct sealing incentives on performance basis: contractors will be paid $1.65 per cfm at 25Pa lowered. This provides a clear incentive for contractors to keep working at air sealing as long as cost-effective sealing can be accomplished (Blankenship *et al*, 2004). Of course, some measure of third-party verification on a sample of jobs, both before and after retrofit, is important to ensure that contractors refrain from gaming the system.

Finally, the evaluation team found that there were a number of mobile homes that used evaporative coolers instead of compressor-based A/C systems, and that the existing systems were frequently in poor operating condition. They recommended repair or replacement with more efficient evaporative coolers where appropriate.

Weatherization: Single family, multi family, and mobile homes

The weatherization program is our nation's longest continuously-supported federal effort to achieve energy conservation. It was initiated in 1975 (before there was a U.S. Department of Energy) in response to the more than five-fold increase in heating oil prices experienced by residents of the Northeast owing to the oil boycott of that era. It has evolved in both scope and technical acumen under DOE and enjoys co-sponsorship of the U.S. Department of Health and Human Services (via the Home Energy Assistance Program) and a variety of state and local organizations, notably including many utility companies.

Longs Peak Energy Conservation, the weatherization program in Boulder, Colorado, is a division of Boulder County government, yet serves a three-county area in Colorado's Front Range. Blower-door aided duct diagnostics plus sealing and insulation has been a routine part of this program's weatherization efforts for more than a decade. As the program has matured, concentration is on all the leaks practical to access in combustion zones plus other large holes in fully-conditioned areas. (Furnaces and hot water heaters are typically located in basements in the Boulder area and ducts are frequently found in crawl spaces.)

Care is taken to avoid backdrafting appliances. In addition, efforts are made to pressure-relieve bedrooms and other areas that can be closed off that are served by supply ducts, but not returns. This work is always accomplished in coordination with other work on the HVAC system, including a clean-and-tune and controls adjustment of the furnace or even replacement if appropriate. In addition, weatherization routinely includes envelope air sealing and insulation. As a consequence, before leaving each newly-weatherized home, a final set of tests to determine (and mitigate, if necessary) worse-case depressurization is accomplished to ensure that no combustion appliance is at risk of being backdrafted.

This whole-house approach thus integrates attention to duct work in the larger context of achieving an energy-efficient home whose systems operate appropriately and health and safety issues are resolved. As a consequence, the incremental cost of supplying duct-related services are in part defrayed by the fact that technicians are already onsite to assess all of a home's energy-related needs and accomplish suitable retrofits. Costs vary by the circumstances of a home, of course, but a mid-sized ranch home with a crawl space routinely involves four to six person hours of labor for a furnace tune-up plus air sealing work on supplies and returns.

Typical material use is two gallons of sealant and half a roll of fiberglass reinforcing tape (about 20 square feet). For the case illustrated, labor costs $25 per hour and material $35 for a total of about $160 for duct sealing work (Richardson, 2005).

In Arizona, where ducts in attics predominate and air handlers are often located in unconditioned spaces like garages, the weatherization program does more extensive work on ducts, since that is where savings are most likely to be harvested most cost effectively. As part of the audit procedure, weatherization technicians perform a two-part blower door test, measuring flow at 50 pascals house pressure (1) with ducts configured as found and (2) with both supply and return ducts temporarily sealed at their registers. The difference is proportional to duct leakage to the outside of the envelope. This is followed by a pressure pan test at each grille in the system in turn with the blower door depressuring the home to 50 pascals. The pattern of pressure readings emerging from the pressure pan measurements is helpful in locating leakage areas, which tend to be close to registers with highest pressure readings. The net result is a strategy for tactical duct sealing that is informed by a duct register pressure map.

Toward estimating the cost effectiveness of duct sealing work—and making practical decisions about when to stop—Charlie Gohman of the Energy Office of the Arizona Department of Commerce developed some rules of thumb based on heating and cooling losses due to duct leakage in Arizona's six climate zones (Gohman 2005). It begins with an estimate of the present value of reducing 100 cfm of duct leakage at 50 Pa to the outside of the conditioned envelope (Table 3).

Table 3. Present value of 100 cfm reduction in duct leakage to the outside of the conditioned envelope when conventional air conditioning is installed

Present Value of 100 CFM reduction	Climate Zone 1 (Flagstaff)	Climate Zone 2 (Phoenix)	Climate Zone 3 (Sedona)	Climate Zone 4 (Tucson)	Climate Zone 5 (Winslow)	Climate Zone 6 (Yuma)
Heating	$570	$65	$250	$70	$280	$35
Cooling	$10	$450	$80	$300	$100	$870
Total	$580	$515	$330	$370	$380	$905

Source: Charlie Gohman, Arizona Department of Commerce

Note that Arizona has a wide range of weather regions. The Flagstaff area has more heating degree days (7500) than does much of Upstate New York and very little need for cooling. On the other hand, Phoenix has 3891 average cooling degree days, and in 1992 had 4811 cooling degree days and 115 days in which the temperature exceeded 100°F (Pedalino 2005).

To simplify, a person-hour of crew work spent air sealing ducts is counted as $50, a figure that takes into account project overhead as well as materials. Generally, weatherization crews work in pairs for this kind of work, so an hour spent by a team doing duct air sealing costs $100. Thus the crew could cost effectively work over three hours to achieve 100 cfm of duct leakage in Zones 3, 4, and 5, five hours in zones 1 and 2, and a whole day in the Southwestern desert, Zone 6. When ducts are quite leaky, initially it is usually easy to achieve more leakage savings per unit of labor than the numbers shown in Table 1. However, as sealing is achieved, pickings get slimmer, so the table is useful in helping to decide when to stop work.

Aeroseal and Weatherization

The Oak Ridge National Laboratory conducted an evaluation of the Aeroseal technique, comparing it with "best practice" duct sealing accomplished using duct blasters and other diagnostic techniques, manually sealing all leaks practical to seal. Crews performing the work were from five experienced weatherization agencies in five states: Iowa, Virginia, Washington, West Virginia, and Wyoming. Pre-retrofit duct leakage to the outside in the 80 single family homes examined averaged about 500 cfm at 25 pascals, the canonical pressure measurement in widespread use in the industry. "Best practice" resulted in an average reduction of 54%, while the Aeroseal technique averaged 63% to 74% (depending on where the pressure in the duct was measured). In addition, labor hours with the Aeroseal technique were about 65% of "best practice." When some ducts were outside the conditioned envelope, savings-to-investment ratios (SIRs) averaged 4.7 with Aeroseal, 3.4 with "best practices." With all homes taken into account, Aeroseal achieved SIRs of 2.9 versus 2.1 for best practices (Ternes 2002).

These calculations assume that labor costs associated with the not-for-profit weatherization program apply to both the Aeroseal and "best practices" duct work. In the private sector, there is a need to amortize the $20,000 franchise fee, pay for the cost of sales and equipment, and make a profit. Accordingly, labor rates for private sector Aeroseal work tend to be much higher, which lowers SIRs substantially.

New Homes Programs

Tucson Electric Power Program

Tucson Electric Power (TEP) is an investor-owned utility in Tucson, Arizona. Its Guarantee Home program was designed to include the steps shown by building science research to be key in constructing homes that are healthy, safe, comfortable, durable, and affordable. TEP guarantees that its homes will cost less than some maximum amount to heat and cool for the year, expressed to customers in dollars per day. In practice this runs from $0.80 per day for 900 square foot homes built by Habitat for Humanity to $4.00 per day for 10,000 square foot mansions constructed by custom builders. More typical homes, like 1,850 square foot structures constructed by production builders, are guaranteed to cost less than $1.60 per day for space conditioning (Figure 3).

Source: TEP

Figure 3. The guarantee for this new home maintains that costs for heating and cooling energy will not exceed $1.33 per day.

Behind the scenes, TEP's staff performs an analysis of builders' plans (using Manual J software), tweaking details until the new homes they represent show strong promise for coming in at 40 to 50% better than homes built to Tucson's energy code (IECC 2000). The utility works with 57 builders in the Tucson area that participate in the TEP Guarantee Program to ensure that homes are efficient, healthy, and comfortable. This includes duct sealing (<3% of the conditioned floor area leakage expressed in cubic feet per minute of flow at 25 pascals), properly-installed insulation, envelope sealing (<0.3 natural air changes per hour), correct sizing of HVAC equipment, pressure balancing (frequently requiring the installation of additional return air paths), and fresh air ventilation systems that slightly pressurize the tight envelopes.

TEP offers participating builders incentives that can be used to help offset additional building costs or for advertising. The company conducts advertising for the builders that includes radio, TV, newspaper, bill stuffers, internet, a variety of quarterly publications, and on-site sales material. Details on this program are available on SWEEP's web site (Kinney 2003).

Utah Power Initiative

There are over 21,000 new dwelling units being built in Utah each year, but well less than 3% are ENERGY STAR rated. There were 528 homes that were ENERGY STAR rated in 2004, 62 % by a single builder, Ence Homes, and another 25% by SunCor Development (EPA 2005). In order to increase the market share for ENERGY STAR (or better) new homes, Utah Power[1] has developed a new homes program that was launched in the spring of 2005. Its aim is to stimulate the construction of "ENERGY STAR plus" homes. In addition to meeting the ENERGY STAR criterion of a Home Energy Rating System (HERS) score of 86, three other requirements are central to the new program: air conditioning units must have a SEER 13 or better or use central evaporative coolers; windows must have a U value of 0.35 or lower plus a solar heat gain coefficient of 0.40 or lower; and ducts much be wholly within the envelope or be tightly sealed (to a measured air leakage of 5% or less).

Utah has passed 2003 International Energy Conservation (IECC) commercial and residential energy codes for the whole state. Both the "Component Performance Approach" (Chapter 5) and the "Simplified Prescriptive Requirements" (Chapter 6) of the 2003 Residential Energy Code call for sealing ductwork using mastics and tapes meeting the requirements of UL 181A or UL 181B, but do not specify the degree of air sealing required (IECC 2003). The code does call for R-8 duct insulation for supply ducts outside of the envelope, R-4 for return ducts in attics, and R-2 insulation for return ducts in such unconditioned spaces as basements, crawl spaces, and garages. The new program in Utah is specifying R-11 for all ducts in attics and R-8 for ducts in other unconditioned spaces, both substantial enhancements over code.

It is believed that one consequence of this program will be to stimulate builders to keep ducts within the conditioned envelope, the most energy-efficient solution to the duct energy loss problem. For the others, a testing regime using duct blasters is being instated. In the interests of both training and quality assurance, the plan is to work closely with builders at the outset. Accordingly, 100% of the first few homes built under program will be tested, then, for production builders who appear to have mastered the process, testing will be dropped back to a 15% sample of new homes. Present plans are to test 100% of the homes produced by custom builders participating in the program (Baylon 2005).

Table 4 shows program cost and savings projections over the first five years of the program.

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[1] Utah Power is a subsidiary of PacifiCorp, which has 1.5 million customers in the U.S. PacifiCorp merged with Scottish Power in 1999. Utah Power serves about 600,000 households.

Table 4. Utah Power ENERGY STAR new homes program goals

Year	Single Family	Multi Family	Total Utility Costs	Annual Savings MWh	Average Demand Savings (MW)
1	350	12	$1,405,595	739	1.0
2	1,192	588	$2,026,029	3,286	4.5
3	1,579	750	$2,089,147	3,630	5.0
4	2,124	750	$2,365,348	4,710	6.4
5	2,396	750	$2,543,973	5,201	7.1
Totals	7,641	2,850	$10,430,092	17,566	24.0

Source: Utah Power 2005

These projections are based on an estimated average savings of 1,870 kWh/yr for single-family dwelling units and 1,151 kWh per year for multifamily dwelling units. By the fifth year of the program, a penetration of 10% of new homes built is anticipated. In addition to achieving a total of 17.5 GWh of electric energy savings in the fifth year of the program, 24 MW of summer peak demand savings is predicted.

An extensive recruitment and training effort is anticipated to stimulate builders to master and adopt a range of energy-efficient building techniques and fully participate in the program. In addition to subsidized training for construction workers, incentives averaging about $420 per dwelling unit will be paid directly to builders who participate in the program.

Energy Codes

Energy codes can be very effective, relatively low-cost instruments for raising the level of energy efficiency in both new homes and extensive retrofits whose permitting processes include meeting energy code requirements. Accordingly, in the context of duct-related programs and policies, it is useful to examine how current energy codes address duct issues and look at what innovations are in the offing.

The 2003 International Energy Conservation Code (IECC 2003), which has been adopted and is in force in most jurisdictions in the Southwest, specifies no duct sealing tightness levels for low-pressure duct systems of the kind routinely found in residential structures (pressures less than or equal to 500 Pa or two inches of water). In particular, in the "Component Performance Approach" Chapter 5 of the residential code, Section 503.3.3.4.3 reads as follows:

> *Sealing required. All joints, longitudinal and transverse seams, and connections in ductwork shall be securely fastened and sealed with welds, gaskets, mastics (adhesives), mastic-plus-embedded-fabric systems or tapes. Tapes and mastics used to seal ductwork shall be listed and labeled in accordance with UL 181A or UL 181B. Duct connections*

to flanges or air distribution systems equipment shall be sealed and mechanically fastened. Unlisted duct tape is not permitted as a sealant on any metal ducts.

On the other hand, the code does have specific insulation requirements that are a function of annual heating degree days (Table 5).

Table 5. Minimum Duct Insulation (source: IECC 2003, Table 503.3.3.3)

Annual Heating Degree Days	**Insulation R-Value (h * ft² * °F)/Btu**			
	Ducts in unconditioned attics or outside building		Ducts in unconditioned basements, crawl spaces, garages, and other unconditioned spaces	
	Supply	Return	Supply	Return
< 1,500	8	4	4	0
1,500 to 3,500	8	4	6	2
3,501 to 7,500	8	4	8	2
>7,500	11	6	11	2

The table notes specify that insulation on return ducts in basements is not required.

These insulation values are unduly low, particularly in cases such as the Southwest where a great deal of duct cross sectional area is in attics where it is exposed to high temperature differences during the cooling season whether the air handler is running or not. This issue was analyzed in the companion technical piece to this document. When ducts in attics in the Southwest are insulated to R-30, annual savings over ducts insulated to only R-4 average over $100 per year.

California's Title 24 Energy Code calls for insulating ducts to R = 6.3 for ducts on the exterior of buildings and R = 2.1 for attics, garages, crawl spaces, walls, and within floor-ceiling spaces when such spaces are exposed to unconditioned air. The exception is in high heating degree day zones (over 8001) where R = 4.2 is required of ducts in these spaces.

Concerning air sealing of ducts, Title 24 was structured the same way as IECC codes (seal, but with no specification on limits to tightness) until the passage of California's Energy and Reliability Act of 2000. This mandated that all ducts in new homes be tested and sealed if necessary to a leakage rate that is 6% of the HVAC fan volume or less, with testing performed by a certified Home Energy Rating System (HERS) rater. The testing is a prescriptive requirement in Title 24, which can be avoided with the performance method for meeting code. As an alternative to duct sealing and testing, builders can install higher-efficiency HVAC equipment and higher-performance glazing; the alternative requirements vary by climate zone. The mandatory duct construction requirements also prohibit the use of building cavities as ducts and disallow the use of duct tape (Abbay 2005).

A key advantage of California's Title 24 requirement is that duct leakage in new homes must be measured. Prohibition of duct tape is already a part of IECC codes, but the addition of California's requirement prohibiting the use of building cavities as ducts is both desirable and easy to check for compliance.

Recent experience in New York is also instructive. A number of builders in New York State would like to be able to meet the requirements of the State's energy code, a modified version of the IECC 2004 Supplement, without having to bring attic insulation levels to R-49 and (especially) wall insulation levels up to R-20 to R-21 levels (depending on heating zone and construction type). Most builders prefer to build walls with conventional 2 x 4 framing on 16 inch centers and there is strong resistance to change in this regard. Additionally, current practice and economic realities of residential construction in some areas of New York State limit builders to the same 2x4 construction scheme to maintain competitiveness and profitability. For that reason, in the Energy Technical Committee proceedings of New York's energy code update process, builders rejected the new simple prescriptive tables in the new 2004 IECC-based upgrade. Instead they asked for and were granted the retention of the REScheck software from the current New York code (which is based on IECC 2000) in order to retain the flexibility to trade off and down to the 2x4 baseline. Accordingly, there is a move afoot to allow trading off the wall and attic insulation requirement for other measures that are more stringent than current code requirements.

Following this logic, three beyond-code measures are under consideration by code officials for this trade off: reducing air leakage of the envelope; raising the efficiency of the heating system; and lowering the air leakage of the ducts. Each trade off would allow ceilings to be insulated to only R-38 (or R-30 in the most moderate climate zone in New York) and walls to R-13.

The duct requirement under consideration calls for duct leakage to be reduced to 6% of conditioned floor area in square feet measured using a duct blaster that pressurizes the duct system to 25 pascals while maintaining the pressure difference between the inside and outside of the envelope at zero using a blower door. The requirement includes formal documentation of the duct testing process.

Projections of savings are based on the assumption that overall duct leakage of 15% of the floor area (expressed as cfm leakage at 25 Pa) would be the case without the additional duct air sealing work. ACEEE estimates that 9% heating savings will result from the duct measure, 70 to 100 therms (depending on weather region) with an average size new home (Nadel 2005). Costs are estimated at $250 per home, but the analysis was run with cost estimates of both 50% and 100% higher than this estimate in the interests of keeping the analysis conservative. With these assumptions, paybacks in energy savings with local fuel costs range from 2.5 to 5 years. (DeWein 2005).

As of the present writing (spring of 2005), these trade offs have been approved by New York's full codes technical committee and the New York State Code Council (which includes builders), and is slated to move to regulation after public hearings this Spring. It should become part of the New York State Energy Conservation Construction Code (based on the IECC 2004 energy code). Plans are afoot to train both builders and code officials in details of the trade-off options.

Policy and Program Recommendations

Codes

Most jurisdictions in Southwestern States in which substantial new residential construction is underway have relatively up-to-date IECC codes on the books, some of which have been incorporated only recently (see www.swenergy.org). Unfortunately, although the residential IECC code urges air sealing of ducts and is specific about the mechanical criteria material used in achieving duct sealing must meet, it does not quantify thresholds of acceptable duct leakage. Both California and New York energy codes have taken steps to remedy this problem, and are thereby establishing precedents that other states or (preferably) national code-making bodies may emulate in future revisions of energy codes.

As regards duct insulation outside of the conditioned envelope, no present energy codes are stringent enough, particularly for cooling-dominated climate areas like much of the Southwest where ducts in attics predominate. To carefully air seal and insulate an attic from the conditioned space below, then punch holes in it to run ducts carrying 50°F air whose R-value is only 4 or so through 140°F attics wastes well over 1,000 kWh per year in typical Southwestern homes. Further, losses are at a maximum on the hottest day of the year when utility companies typically have major costs to meet the demand on their grids. Addressing these problems through codes could be very helpful in moving builders to adopt better practices.

We recommend crafting codes in ways that will stimulate keeping ducts out of unconditioned spaces altogether—and specify stringent air sealing and insulating standard for ducts outside of conditioned spaces. In particular, we recommend that standards be adopted that ducts must be wholly within the envelope or be sealed to a measured air leakage of 5% or less. In addition, both supply and return ducts should be insulated to R-11 in attics and other spaces completely outside of the envelope and to R-8 in unconditioned areas. (These are the standards adopted in the new Utah Power initiative; see above, pp 15-17.)

Utility and other Programs

Most—not all—distribution systems in homes are much less efficient than they could be and some are downright dangerous. Further, like arteries and veins in the body, distribution systems interact with most other systems in dwellings: the HVAC system; the envelope; and many appliances, especially those that are vented, like furnaces, hot water heaters, dryers, and fans. Two policy-relevant inferences follow from these realities. (1) Those who work on ducts need to be thoroughly acquainted not only with testing and fixing ducts, but also with assessing their interactions with these other systems to make sure bad things don't happen in the home. (2) It is likely to be more cost effective to an energy-saving program to accomplish more than duct efficiency measures while at a home, even if the program's primary focus is on ducts. This generalization applies to both new and retrofit home programs.

Retrofit

Co-sponsor weatherization programs
The advantage here is that weatherization program operators are already up to speed on accomplishing duct retrofits in the context of doing comprehensive work that saves energy cost effectively. Co-sponsoring DOE weatherization projects also gives the co-sponsoring agency (for example, a utility, a local or state energy office) some say in matters of particular interest—for example, focusing on electric energy savings and reporting to the sponsoring agency estimates of savings achieved by customers served. From the weatherization agency point of view, the additional funding makes it possible to serve more people. The disadvantage is that weatherization programs serve primarily lower-income customers, as is consistent with their mandate from DOE, so higher-income households are not served by the program. However, a number of local agencies, which are usually not-for-profit organizations, establish for-profit subsidiaries that can serve the larger population of the private sector.

Weatherization agencies can usually be counted upon to do good-quality, cost-effective duct work, but most agencies air seal using manual techniques, not the Aeroseal approach. Accordingly, unlike the Aeroseal approach, sealing is limited to places which can be accessed by technicians. As the Oak Ridge study of the Aeroseal approach that involved five weatherization agencies—one from Wyoming—showed, weatherization agencies are fully capable of mastering the art of air sealing ducts with the Aeroseal technique. Accordingly, with the stimulus of additional funding, many local weatherization agencies would probably be willing to extend their services to include the Aeroseal approach in circumstances where it is likely to be cost effective.

Another advantage of dealing with weatherization agencies is that they are already in a home accomplishing other energy retrofit measures. Their approach is to carefully assess a home, looking for all retrofit measures that are cost effective from the customer's point of view. When ducts need some attention, but perhaps not a full-blown Aeroseal approach, this can be accomplished. Thus, the swing of the bat can be matched to the speed of the pitch—and all appropriate conservation work can be cost effectively matched to the needs of the dwelling.

Stimulate for-profit HVAC contractors to accomplish duct sealing and insulating work.
Both the Florida utilities model and the SMUD model involve ensuring that contractors are well trained in the craft of duct repair, and in both cases contractors are certified and utilities play active roles in promoting the programs and providing incentives by writing down costs to customers. The Florida utilities model is both less costly and more cost effective, however, since it does not employ the more expensive Aeroseal process. Some savings are given up, but programmatically it may be better in hot areas in the Southwest in which ducts are predominately found in attics to adopt the Florida model of repairing ducts, replacing them when necessary, and air sealing by best-practices manual techniques using mastic and fiberglass tape. This should not preclude the Aeroseal approach if individual circumstances particularly favor this option. Increasing insulation in the attic via the Ultimate R or similar approach would almost certainly be cost effective as well. (See the adjoining technical report, "Duct Systems in Southwestern Homes: Problems and Opportunities," at www.swenergy.org.)

Training a cadre of competent HVAC technicians whose businesses are fully functional in the rationale for duct sealing and insulation as well as in tactics for measuring and accomplishing the work professionally is certainly worthwhile, and both utilities and energy offices could co-sponsor such efforts. After a handful of contractors have mastered the craft and are certified, a campaign could be launched to promote the service, whose scope should have duct work as a focus, but be oriented to saving energy through HVAC-related retrofit work more generally. This could include cooling and heating system assessment, adjustments, control settings, and, where appropriate, more substantial retrofits along with duct sealing and insulation. Health and safety as well as enhanced energy efficiency, comfort, and energy bill savings should become key elements in marketing the program. An approach that includes training and certifying contractors, vigorous marketing (with a focus on high users, whose ducts and HVAC systems are quite likely to need attention), coupled with incentives for both the assessing and retrofit work could be in the interest of all parties.

Launch DSM Programs for Mobile Homes. This concept is similar to the successful programs conducted in Oregon, in which contractors are thoroughly trained to perform specialized duct-related work on mobile homes. Building on the strengths of the California Hard-to-Reach Mobile Home Energy Savings Program, it may be worthwhile to extend the program's scope to include tactical envelope air sealing, in part because a blower door test is already integrated into the duct sealing process so the incremental cost in contractor time (and additional cost in air sealing materials) would likely be small in relation to savings achieved. In this same vein, adding a test of the energy consumed by the refrigerator while at the site doing other work (A/C tune up, set back thermostats, low flow devices) would be simple and inexpensive, as would be changing out incandescent bulbs for suitable CFLs.

New Construction

Stimulate Energy-Efficient Construction

The Utah program merits being watched closely with a view to emulating its best features in other fast-growing areas of the Southwest, for it includes incentives to produce ENERGY STAR Plus homes whose duct performance is likely to be exemplary. This approach has the additional advantage of including duct efficiency in coordination with other measures likely to extend home performance beyond what is achieved with ordinary ENERGY STAR homes.

Tucson Electric Power has gone the additional step of guaranteeing savings achieved by home builders participating in their efficiency program, which prominently includes duct sealing and insulating, as well as pressure balancing. The duct-sealing limits are specified as less than 3% of the conditioned floor area leakage expressed in cubic feet per minute of flow at 25 pascals as measured with a duct blaster (Kinney 2003).

Co-sponsor research and demonstration projects aimed at changing construction techniques in the Southwest to solve duct-related problems altogether. Working with Building America contractors and production builders, research and demonstration projects that may be usefully undertaken include:

- Systems with ducts wholly within the envelope, with closed combustion HVAC centrally located, short supply and returns, pressure relief via the deKieffer or similar system, with careful attention to noise abatement and good distribution.

- Designs in which the space conditioning function is separated from the ventilation function, allowing for getting rid of most ducts. We envision radiant heating ***and cooling*** of an insulated slab, with heating via a simple active solar system (which also produces domestic hot water) backed up with a small, condensing boiler, and cooling via mini-tower, evaporative cooling. Ventilation would optimally be achieved via air-to-air heat exchanger drawing from baths and kitchen, supplying fresh air to the master bedroom and family space.

- A variation on the theme above, with a district system for supplying chilled and warm water to a neighborhood. This would minimize mechanical equipment in homes, and is consistent with a solar front end with a single condensing boiler with a high turn-down ratio as back up.

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Appendix A

Resources

- Program design and evaluation assistance to utilities considering adding new DSM initiatives in the duct efficiency and related areas is available from the Building America program, headquartered at the National Energy Renewable Laboratory in Golden, CO. Contact Ren Anderson at 303-384-7433, email ren_anderson@nrel.gov.

- Energy Star information on ducts, duct technology, duct programs, and a number of useful links is available at http://www.energystar.gov/index.cfm?c=ducts.pr_ducts.

- The Consortium for Energy Efficiency (CEE) has papers and specifications for energy-efficient HVAC installations and related information at http://www.cee1.org/resid/rs-ac/hvac.php3. Particularly useful are downloadable specifications for duct insulation and sealing prepared by Jim O'Bannon of Richard Heath and Associates for the Pacific Gas and Electric Company.

- "Thermal Energy Distribution" by building scientists at the Lawrence Berkeley National Laboratory is an excellent overview with many links to other relevant documents http://epb1.lbl.gov/EPB/ducts/.

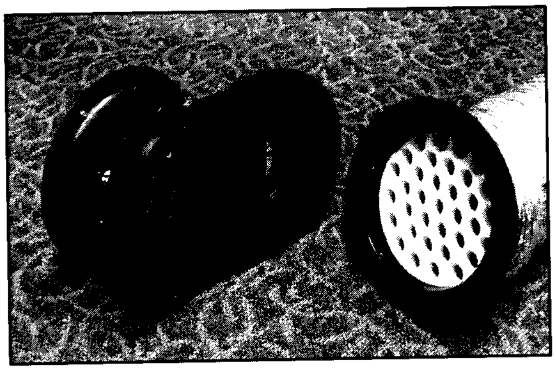
- A "Best Practices Guide" for residential HVAC retrofits is a useful DOE document that includes input from many parties is available at http://epb1.lbl.gov/EPB/ducts/HVACRetrofitguide.html.

Field Calibration Check Procedure

Minneapolis Duct Blaster System (with DG-700)

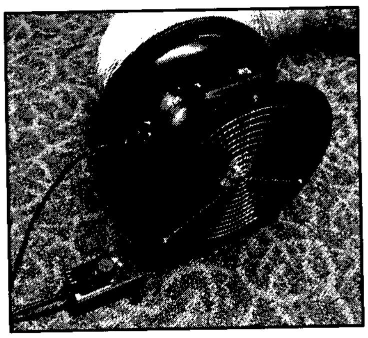
The following procedure uses a Duct Blaster Field Calibration Plate to perform a field calibration check on your Series B Minneapolis Duct Blaster System (with DG-700 gauge). The field calibration plate is designed to simulate a duct leakage test with a leakage rate of 106 CFM @ 25 Pascals.

1. Set up the Duct Blaster fan for depressurization testing, with **Ring 3** installed:

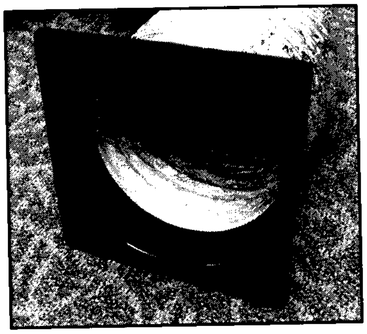


   - Install the white foam flow conditioner inside the round transition piece (this must always be installed when depressurization testing).
   - The round transition piece (with attached flex duct) should be connected to the inlet side of the Duct Blaster fan (using the fan connecting trim), with Ring 3 installed between the round transition piece and the fan inlet. Be sure the connecting trim is securely fastened all the way around the inlet flange of the Duct Blaster fan.
   - Be sure the nozzle on Ring 3 is pointing toward the fan motor.

2. Connect the Duct Blaster speed controller to the fan, and plug the speed controller into a power outlet (the controller should be turned off).



3. Install the square transition piece into the open end of the flex duct. Tightly secure the square transition piece to the flex duct using the velcro strap on the end of the flex duct.



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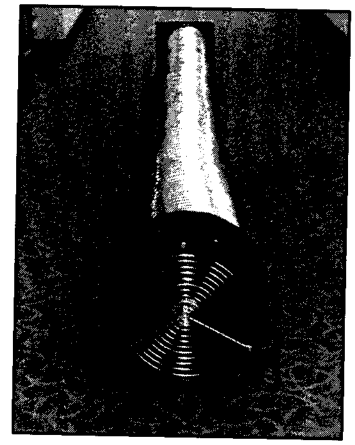
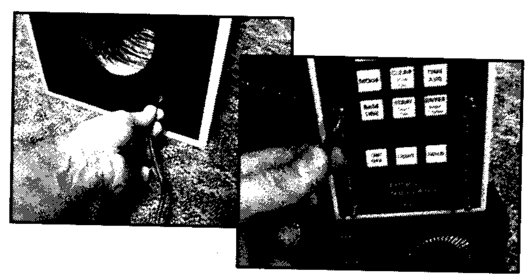
4. Fully extend the flex duct away from the fan. Be sure the flex duct is straight, completely extended, and there are no kinks or bends in the flex.

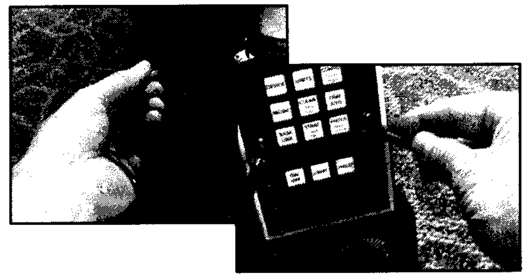


5. Tape the field calibration plate to the end of the square transition piece:
   - Line up the outside edge of the calibration plate with the outside edge of the square transition piece.
   - Orient the calibration plate so that the label side of the plate (textured surface) is facing out and the smooth side is facing toward the inside of the flex duct.
   - Tape the calibration plate to the square transition piece along the entire seam.
   - Make sure there are no obstructions in front of the calibration plate.

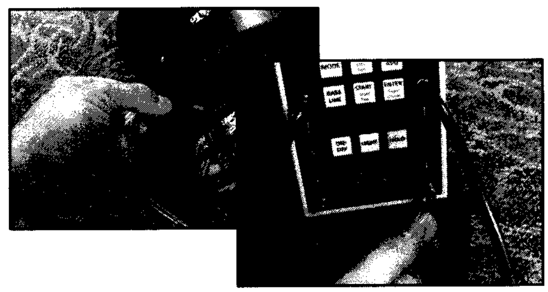
6. Connect tubing to the DG-700 gauge:
   - Connect a piece of tubing from the pressure tap on the calibration plate to the Channel A Input tap.



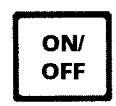
- Connect a 2nd piece of tubing from the brass tap on the Duct Blaster fan to the Channel B Input tap.



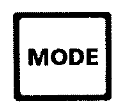
- Connect a 3rd piece of tubing from the plastic tap on the round transition piece to the Channel B Reference tap.



7. Turn on the DG-700 gauge and enter the correct settings:
   - Turn on the gauge by pressing the **ON/OFF** button.

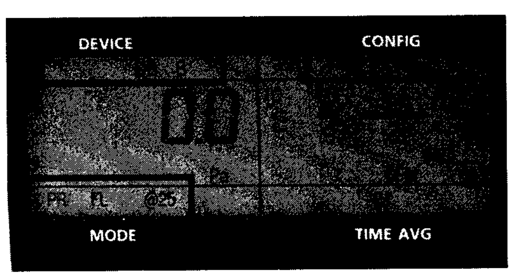


   - Push the **MODE** button 3 times to place the gauge in the **PR/ FL @25** mode (**PR/ FL @25** should be displayed in the MODE window).



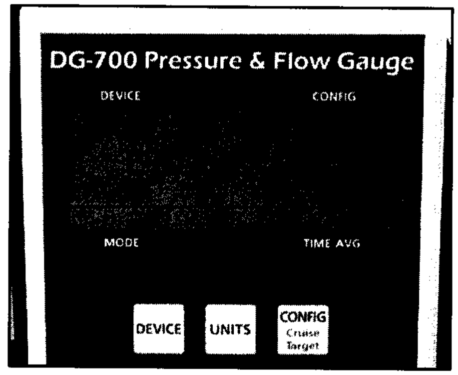
   - Press the **DEVICE** button 4 times to select the Series B Duct Blaster fan (**DB B** should be displayed in the DEVICE window).

   - Press the **CONFIG** button 3 times to select Ring 3 as the current configuration (**C3** should be displayed in the CONFIG window).



   - Make sure the DG-700 is located away from the air flow that will be exiting the Duct Blaster fan.

8. Turn on the Duct Blaster fan and take a flow reading from the field calibration plate:



   - Turn on the Duct Blaster fan by slowing turning the knob on the fan controller clockwise.
   - Adjust the fan until the pressure displayed on **Channel A** is 25 Pa (between 24.5 Pa and 25.5 Pa is acceptable).
   - Once the fan speed is adjusted appropriately, set the DG-700 gauge to take 10 second average readings. This done by pressing the **TIME AVG** button twice (**10** should be displayed in the TIME AVG window).
   - After 10 seconds, read the flow value displayed on **Channel B** and write it down on a recording form (a sample form is located at the end of this document). In the photo to the right, the flow reading is 105 CFM.

9. Determine if flow reading is within the acceptable range:
   - If the flow reading is between 103 and 109 CFM (while Channel A is between 24.5 and 25.5 Pa), the Duct Blaster System (fan and gauge) passes the field calibration check. No additional calibration of the System is needed at this time.
   - If the flow reading is less than 103 CFM, or greater than 109 CFM, then the Duct Blaster System fails the field calibration check, and the operator should consult the Troubleshooting Guide below.

Troubleshooting Guide (Duct Blaster System has failed the field calibration check).

a) Make sure the tubing connections are correct (see Item 6 above).
b) Check tubing for leaks or blocked or pinched tubing. Replace pinched or leaky tubing.
c) Make sure you have correctly installed Ring 3 on the Duct Blaster fan in the depressurization mode (see Item 1 above).
d) Make sure you have the correct settings entered into the DG-700 (see Item 7 above). Also be sure that air flow from the Duct Blaster fan is not blowing on the DG-700 gauge.
e) Make sure the flex duct is straight and fully extended (see Item 4 above).
f) Make sure there are no obstructions in front of the calibration plate.
g) If the flow reading is high (greater than 109 CFM), check for leaks in the flex duct. Seal flex duct leaks if found, or replace flex duct.

Repeat the field calibration check. If the Duct Blaster System still fails, send the Duct Blaster System (including the DG-700 gauge) to The Energy Conservatory for repairs and/or calibration adjustment. Please include a letter indicating the flow value measured during your field calibration check, as well as billing, shipping and contact information.

Field Calibration Check Form
Series B Minneapolis Duct Blaster (with DG-700 Gauge)

Company: ____

Gauge Serial # ________________ **Last Factory Calibration Date** ________________

Duct Blaster Fan Serial # ____________

Date of Field Calibration Check	Technician	Duct Pressure Reading (Channel A)	Calibration Plate Flow Reading (Channel B)	Is Flow within Acceptable Range (103-109)?
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No
				Yes No

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B3

Procedure for Field Checking the Model 3 Blower Door and Series B Duct Blaster Fans

1. Introduction

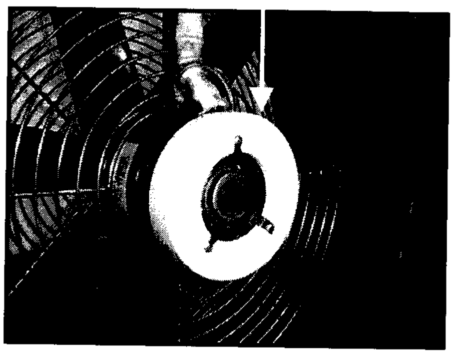
Model 3 Blower Door and Series B Duct Blaster fans maintain their calibration unless physical damage occurs to the fan. Conditions which could cause the fan calibration to change are primarily damaged flow sensors, leaks in the flow sensor or tubing running from the flow sensor to the fan pressure tap, or improper positioning of the flow sensor relative to the fan housing. These conditions are easily detected and should be tested for on a regular basis.

2. Checking for a Leaky or Damaged Flow Sensor

a. Model 3 Blower Door Fan

Model 3 Blower Door fans use a round white plastic flow sensor that is mounted on the end of the fan motor opposite the fan blades.

Model 3 Blower Door Flow Sensor



First visually confirm that the flow sensor is not broken or deformed due to impact. Check that the flow sensor is firmly attached to the motor using the 3 metal attachment clips.

Next, perform a test for air leaks in the flow sensor and the tubing connecting the sensor to the fan pressure tap (this test is easier if you first place the fan in an elevated position such as on a bench top or table.)

1) Attach a piece of tubing to the pressure tap on the Blower Door fan electrical box. Leave the other end of the tubing open.
2) Find the 4 intentional sensing holes in the outside rim of the flow sensor (the sensing holes are located at 2, 4, 8, and 10 o'clock). Temporarily seal the 4 sensing holes by carefully covering them with masking tape.

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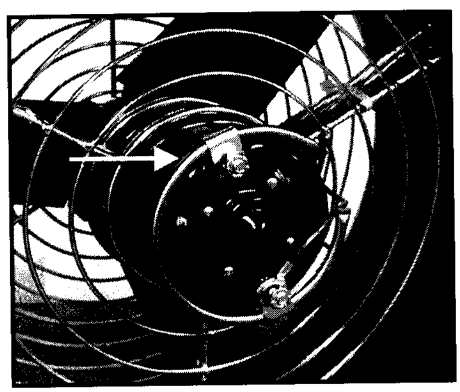
3) Create a vacuum in the tubing connected to the fan pressure tap by sucking on the open end of the tubing. While creating a vacuum in the tubing, place your tongue over the end of the tubing. The vacuum in the tubing should cause the end of the tubing to stick to your tongue. If the tubing remains stuck to the end of your tongue for at least 5 seconds, the fan and flow sensor pass this part of the test. (Be sure to remove the masking tape from the flow sensor holes.)

If a vacuum can not be created (i.e. air is easily sucked through the tubing), or a vacuum will not persist for at least 5 seconds (i.e. the end of the tubing will not stick to your tongue for at least 5 seconds), there is a leak in either the flow sensor itself or in the tubing that connects the flow sensor to the fan pressure tap. Contact TEC for help in further diagnosing the problem.

b. Series B Duct Blaster Fan

The Duct Blaster uses a flow sensor manufactured out of thin stainless steel tubing. The flow sensor is permanently attached to the end of the fan motor opposite the fan blades.

Series B Duct Blaster Flow Sensor



First visually confirm that the sensor is not broken or deformed due to impact. Check that the sensor is firmly attached to the motor. Next, perform a test for leaks in the sensor and the tubing connecting the sensor to the fan pressure tap.

1. Attach a piece of tubing to the brass pressure tap on the Duct Blaster fan housing. Leave the other end of the tubing open.
2. Find the 3 intentional sensing holes in the flow sensor - they are evenly spaced on the back side of the sensor. Temporarily seal the 3 holes by covering them with masking tape.
3. Create a vacuum in the tubing connected to the fan pressure tap by sucking on the open end of the tubing. While creating a vacuum in the tubing, place your tongue over the end of the tubing. The vacuum in the tubing should cause the end of the tubing to stick to your tongue. If the tubing remains stuck to the end of your tongue for at least 5 seconds, the fan and flow sensor pass this part of the test. (Be sure to remove the masking tape from the flow sensor holes.)

If a vacuum can not be created (i.e. air is easily sucked through the tubing), or a vacuum will not persist for at least 5 seconds (i.e. the end of the tubing will not stick to your tongue for at least 5 seconds), there is a leak in either the flow sensor itself or in the tubing that connects the flow sensor to the fan pressure tap. Contact The Energy Conservatory for help in further diagnosing the problem.

3. Checking the Flow Sensor Position

The position of the flow sensor relative to the inlet of the fan housing is a important component of the fan's air flow sensing system. Because the fan flow sensor is attached to end of the fan motor, the position of the flow sensor can change if the position of the motor changes. If a fan has been dropped, the motor may have shifted from its proper position in the motor mount, or the motor mount itself can sometimes bend. This movement of the motor and flow sensor can degrade the fan calibration.

a. Model 3 Blower Door Fan

To check the flow sensor position, lay the fan on its side with the flow sensor facing up and all flow rings removed. Place a straightedge (such as a heavy yardstick on edge) across the inlet of the fan. Use a ruler to measure the distance from the bottom of the straightedge to the face of the flow sensor (see diagram #1 below). This distance should be in the range of $3/16^{th}$ to $5/16^{th}$ of an inch. If the flow sensor is within this range, the fan passes this part of the field check procedure. If the flow sensor is not in the proper position, contact The Energy Conservatory for further instructions.

b. Series B Duct Blaster Fan

To check the flow sensor position, lay the fan on its side with the flow sensor facing up and all flow rings removed. Place a straightedge (such as a heavy yardstick on edge) across the inlet of the fan. Use a ruler to measure the distance from the bottom of the straightedge to the tip of the motor bearing's domed cover (see diagram #2 below). This distance should be in the range of $5/8^{th}$ to $7/8^{th}$ of an inch. If the flow sensor is within this range, the fan passes this part of the field check procedure. If the flow sensor is not in the proper position, contact The Energy Conservatory for further instructions.

Diagram #1 (Model 3 Blower Door Fan)

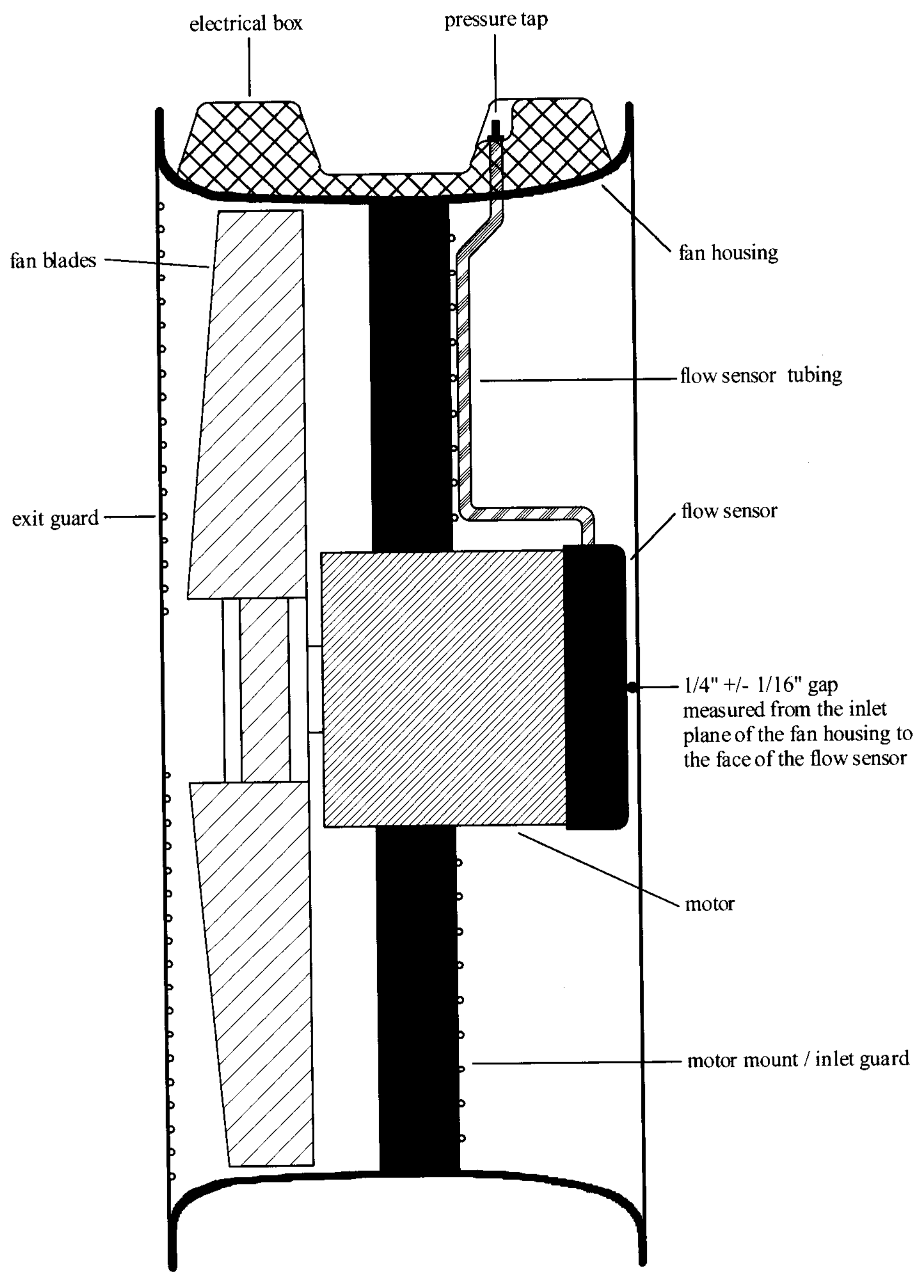
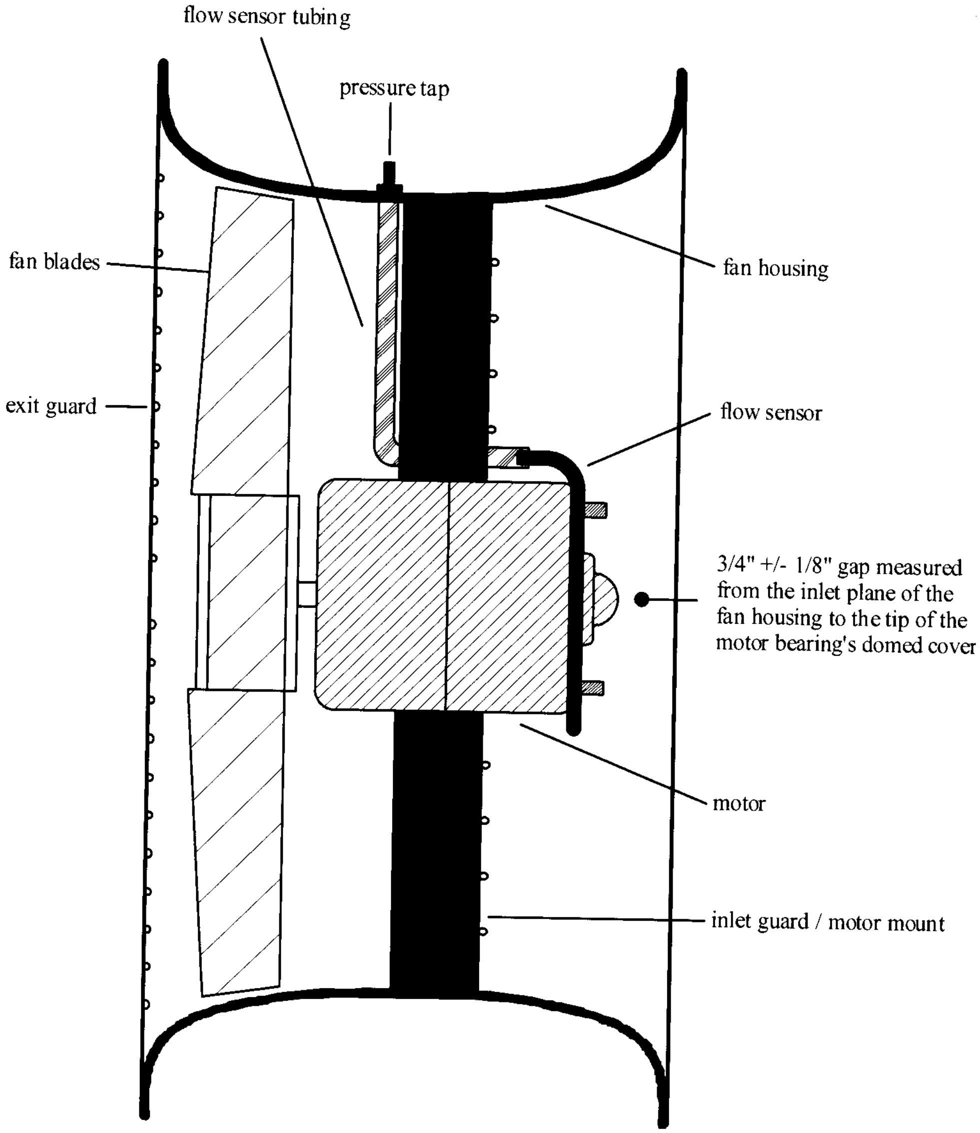


Diagram #2 (Series B Duct Blaster Fan)



4. Other Issues Affecting the Accuracy of Fan Flow Measurements

a. Model 3 Blower Door Fan

Upstream Air Flow Conditions:

The calibration for all Blower Door fans are slightly sensitive to upstream air flow conditions (e.g. orientation of walls, doors, stairs etc. relative to the fan inlet). This is particularly true when measurements are taken using the "open fan" configuration. As a result, follow these simple rules whenever possible.

- It is always best to install the fan in a doorway leading to a large open room. Try to avoid installing the fan in a doorway where there are stairways or major obstructions to air flow very close (1-5 feet) to the fan inlet.
- If the fan must be installed next to a stairway or major obstruction, it is best to take measurements using one of the Flow Rings and not "open fan".
- Always open the inside door and outside storm door as much as possible during the Blower Door test to prevent restrictions to air flow.

Operating Under High Backpressure Conditions:

Note: For most testing applications, backpressure is not a concern and can be ignored.

The term "backpressure" is used to describe the pressure that the Blower Door fan is working against when it is running. Backpressure is determined by measuring the static pressure difference between the air directly upstream of the fan, and the air directly exiting the fan.

Under typical testing applications, the backpressure seen by the fan is simply the test pressure at which the building airtightness measurement is being measured made (e.g. 50 Pascals). However, there are applications where the Blower Door fan could see backpressures that are greater than the test pressure. For example, if the Blower Door fan is exhausting air into a confined area (such as an attached porch), it is possible that the porch area could become pressurized relative to outside creating a backpressure condition that is greater than the test pressure. Although the Blower Door 's flow sensor was designed to be affected as little as possible by variations in backpressure, under certain high backpressure operating conditions (described below) the calibration of the fan can degrade.

High Backpressure Conditions

Model 3 fans can be used in testing applications with backpressures up to 80 Pascals with no significant effect on calibration accuracy. This is true for all fan flow configurations (Open through Ring E), provided that the fan is operated within the accepted flow range for each configuration. Backpressures above 80 Pa can diminish the accuracy of the fan calibration and should be avoided.

b. Series B Duct Blaster Fan

Upstream Air Flow Conditions:

- When using the Duct Blaster fan to conduct a duct leakage depressurization test (i.e. the flex duct is connected to the inlet side of the fan), always position the fan so that the flex duct is stretched relatively straight for about 4 feet in front of the fan.
- When the fan inlet is open to the room, try to install the fan so that there is not a large obstruction within 2 feet in front of the fan.

Operating Under High Backpressure Conditions:

Note: For most testing applications, backpressure is not a concern and can be ignored.

The term "backpressure" is used to describe the pressure that the Duct Blaster fan is working against when it is running. Backpressure is determined by measuring the static pressure difference between the air directly upstream of the fan, and the air directly exiting the fan. High backpressures are typically caused by a large restriction between the Duct Blaster fan and the location where the test pressure is being made.

Although the Duct Blaster's flow sensor was carefully designed to be affected as little as possible by variations in backpressure, under certain very high backpressure operating conditions (described below) the calibration of the fan can degrade.

<u>High Backpressure Conditions</u>

Series B Duct Blaster fans can be used in most testing applications with backpressures up to 100 Pascals with no significant effect on calibration accuracy. This is true for all fan flow configurations (Open through Ring 3), provided that the fan is operated within the accepted flow range for each configuration. The only exception to this rule is for flow measurements below 20 CFM (Ring 3 will measure down to 10 CFM). When measuring flows between 20 and 10 CFM using Ring 3, backpressures should be kept below 40 Pascals. Backpressures above these values can diminish the accuracy of the fan calibration and should be avoided.

One example of an application that could cause high backpressure is when the flexible extension duct is connected to a small, high resistance register. The high resistance register can cause the pressure in the flex duct to be very high (i.e. over 150 Pascals) even if the test pressure in the duct system is only 25 Pascals. Operating the Duct Blaster fan under these operating conditions is not advised. To avoid this problem:

- Always try to avoid connecting the Duct Blaster fan to the duct system using a relatively high resistance connection (such as a small supply register).
- If you are using a high resistance connection and suspect a high backpressure condition, try to measure the backpressure. If the measured backpressure is less than the values listed above, then there should not be a problem. If the flexible extension duct is being used, the backpressure can be easily determined by measuring the pressure difference between the room where the Duct Blaster fan is installed and pressure inside the flex duct (measured from the plastic tap on the round transition piece).

5. General Maintenance Information for Model 3 Blower Door and Series B Duct Blaster Fans

a. Model 3 Blower Door Fan

- Examine the motor cooling holes for excessive dust build-up. Use a vacuum with a brush attachment to remove dust, or blow out the dust with compressed air.
- Inspect housing, blades and guards. Especially note clearance of blade tips relative to the fan housing. There should be about 1/4 inch of clearance.
- Inspect electrical wiring and electrical connections on the fan and the fan speed controller.
- Do not reverse the fan (using the flow direction switch) while the blades are turning. Turn off the fan and wait for it to come to a complete stop before reversing the flow direction.
- For long-term operation, such as maintaining house pressure while air-sealing, use a Flow Ring whenever possible to ensure good airflow over the fan. This will minimize the heating of the fan and is especially important in warmer weather. In particular, do not operate the fan for long periods of time on low speed with open fan.
- Do not run the fan for long periods of time in reverse.
- If the motor gets too hot, it may experience a shut-down due to the thermal overload protection. If this happens, make sure to turn off the controller so that the fan does not restart unexpectedly after it cools down.
- Make sure to press the power plug firmly into the power receptacle on the fan. Failure to do so can cause overheating of the power cord and possible damage.
- Do not use ungrounded outlets or adapter plugs.
- The fan should not be left running unattended.
- Do not operate if the motor, controller or any of the electrical connections are wet.
- Keep people and pets away from the fan when it is operating.
- If the fan housing, fan guards, blade, controller or cords become damaged, do not operate the fan until repairs have been made.

b. Series B Duct Blaster Fan

- Examine the motor cooling holes for excessive dust and dirt build-up. Use a vacuum with a brush attachment to remove dust, or blow out the dust with compressed air.
- Inspect housing, blades and guards. Especially note clearance of blade tips relative to the fan housing. There should be about 1/4 to 1/8 inch of clearance.
- Inspect electrical wiring and electrical connections on the fan and the fan speed controller.
- The Duct Blaster fan motor is not a continuous duty motor and should not be run for extended periods of time (more than 2 hours at one time).
- The fan should not be left running unattended.
- Do not use ungrounded outlets or adapter plugs.
- Do not operate if the motor, controller or any of the electrical connections are wet.
- Keep people and pets away from the fan when it is operating.
- If the fan housing, fan guards, blade, controller or cords become damaged, do not operate the fan until repairs have been made.

Field Check Form
Model 3 Blower Door and Series B Duct Blaster Fans

Company: ______________________________

Fan Model (circle)	Serial Number	Date	Technician	Passed Flow Sensor Leakage Test?	Passed Flow Sensor Position Test?
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No
Model 3 Blower Door Series B Duct Blaster				Yes No	Yes No

Chapter 13 Using the Duct Blaster as a Powered Capture Hood

In addition to measuring duct airtightness, the Minneapolis Duct Blaster can be used as a powered capture hood to measure total air handler flow, as well as air flows through supply and return registers, exhaust fans and other air flow devices.

13.1 Measuring Total System Air Flow (Pressure Matching Method)

This procedure is used to measure total air flow through an air handler. **Note:** If you are using a DG-700, the gauge has a built-in mode (**PR/ AH**) which can be used for making measurements of total air handler flow with a Duct Blaster fan. Refer to the DG-700 manual for specific operating instructions.

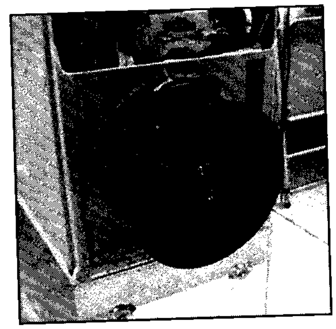
Part 1: Measure the Normal System Operating Pressure (NSOP)

- Turn off the air handler fan.
- Open a window or door between the building and outside to prevent pressure changes in the building during the test.
- If the air handler fan is installed in an unconditioned zone (e.g. crawlspace, attic), open any vents or access doors connecting that zone to the outside (or to the building) to prevent pressure changes in the zone during the test.
- Make sure all supply and return registers are open and untapped. Replace filters if they are dirty (or keep dirty filters in place if you want to measure flow in a "as found" condition).
- Insert a static pressure probe into the supply plenum, or in a main supply trunk line a few feet away from the supply plenum. Make sure the static pressure probe is pointing into the air flow created by the air handler fan.
- Connect a piece of tubing to the static pressure probe. Connect the other end of the tubing to the **Channel A Input** tap on the digital pressure gauge.
- The **Channel A Reference** tap should be connected to the inside of the building, or it can be connected to an unconditioned zone containing the air handler provided that the zone remains at the same pressure as the building during the test.
- Turn on the air handler and measure the Normal System Operating Pressure (**NSOP**) in the duct system using **Channel A**. If the **NSOP** is fluctuating too much to determine the reading, try using the ***5*** or ***10*** second or ***L***ong-term time average setting on the gauge. Record the **NSOP** and turn off the air handler. Do not move the static pressure probe because you will need to use it in Part 3 of this test.

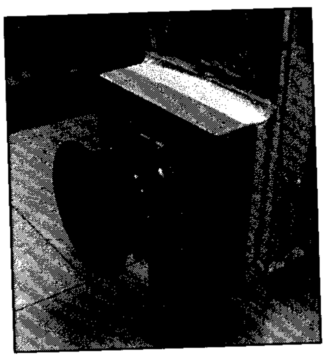
Part 2: Connect the Duct Blaster Fan to the Duct System

The Duct Blaster fan is typically installed at the air handler cabinet. However, if this test is being performed on a single return duct system, and the return ductwork is substantially airtight, the Duct Blaster fan may be installed at the single return.

Option 1: Installing at the Air Handler Cabinet

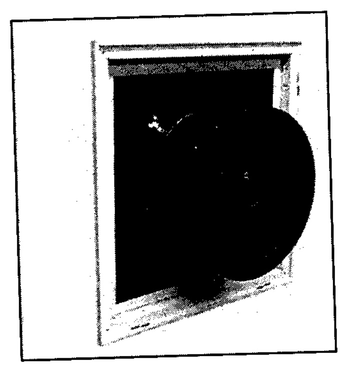


- Open the air handler cabinet access panel. Seal off the return opening in the cabinet from the air handler fan using tape and cardboard.
- Now install the Duct Blaster in place of the air handler cabinet access door as described in ***Section 5.2.b Option 2***. In this configuration, all return air flow will be moving through the Duct Blaster fan, with the return ductwork effectively sealed off from the supply system.
- Connect a piece of tubing to the brass pressure tap on the Duct Blaster fan housing. Connect the other end of the tubing to the **Channel B Input** tap.
- The **Channel B Reference** tap should be connected to the space where the Duct Blaster fan is installed. If the Duct Blaster fan and gauge are located in the same space, leave the **Channel B Reference** tap open.



Note: If the air flow exiting from the Duct Blaster is severely obstructed by the air handler fan or other air handler components, this may significantly reduce the total flow capacity of the Duct Blaster. If this is a problem, try attaching the Duct Blaster fan to the blower compartment access opening using a small cardboard box rather than a flat piece of cardboard. This will tend to increase the Duct Blaster fan flow by providing less restriction to air flow as it enters the air handler blower compartment.

Option 2: Installing at the Single Central Return



- An optional 20" x 20" filter grille attachment panel is available from TEC to provide for quick attachment of the Duct Blaster fan to the filter slot of a single return.
- To use the attachment panel, first open the filter grille door, remove the existing filter, and push the attachment panel into the open filter slot. The H-channel gasket on the edges of the attachment panel should provide an airtight seal between the panel and the filter slot, and should hold the panel in place.
- You may now secure the Duct Blaster fan directly to the attachment panel using the 4 clips mounted on the panel. The clips are pushed down onto the exhaust flange of the Duct Blaster fan.

Note: The Duct Blaster fan can also be attached to the filter slot using cardboard and tape.

Part 3: Match the Normal System Operating Pressure (NSOP)

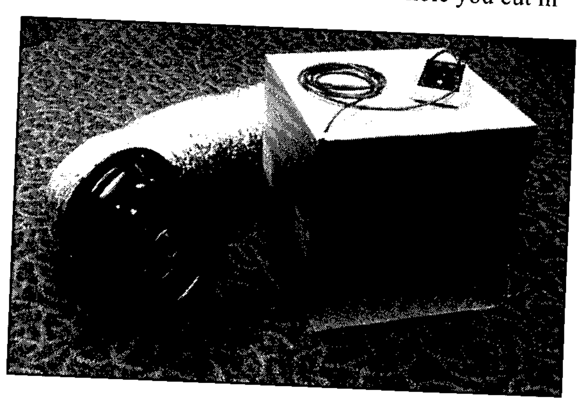
- Turn the air handler fan back on and re-measure the operating duct pressure using **Channel A** (be sure the static pressure probe has not been moved from **Part 1** above). Now turn on the Duct Blaster fan and adjust the fan speed until the operating duct pressure on **Channel A** equals the normal operating duct pressure (**NSOP**) measured in **Part 1** above. Once adjusted in this way, determine the air flow through the Duct Blaster fan by measuring the fan pressure on **Channel B** and using the flow table, or by using the digital gauge's fan flow feature.
- The measured Duct Blaster fan flow is your estimate of the total system air flow including flow through return registers, plus return duct leakage, plus leakage at the air handler access panel. The only component of total system airflow that is not included in this measurement is any leakage on the return side of the air handler cabinet (other than the air handler access panel).

13.2 Measuring Return Register and Exhaust Fan Flows

The first step is to construct a flow box to seal around the return register (or exhaust fan) where you want to make your measurement. One easy option is to use a cardboard box, but the hood from a commercial flow capture hood may also work well. The open end of the flow box or hood should have rough dimensions which are at least 2 times the register dimensions, and the depth of the box should be at least the average of the two opening dimensions.

Part 1: Construct a Flow Box and Make Tubing Connections

- Cut a square hole in the back side of cardboard flow box which is approximately one inch smaller than the dimensions of the square transition piece. Tape and seal the square transition piece over the hole you cut in the box.
- Attach the open side of the round transition piece to the exhaust flange of the Duct Blaster. Connect the open end of the flex duct to the square transition piece on the flow box.



- Install the Flow Ring (on the fan inlet) which you think will provide the proper flow range for the test.
- Punch a small hole (1/4") in one of the corners of the open end of the box and insert a piece of tubing into the hole. Connect the other end of the tubing to the **Channel A Input** tap. The **Channel A Reference** tap should be left open to the room where the register or exhaust fan is located.
- Connect a piece of tubing to the brass pressure tap on the Duct Blaster fan housing. Connect the other end of the tubing to the **Channel B Input** tap.
- The **Channel B Reference** tap should be connected to the space where the Duct Blaster fan is installed. If the Duct Blaster fan and gauge are located in the same space, leave the **Channel B Reference** tap open.

Part 2: Install Flow Box and Zero Out the Box Pressure

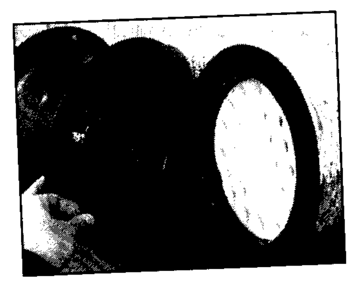
- Turn on the air handler fan (or exhaust fan), and place the flow box tightly over the return register (or exhaust fan grill). If the wall or ceiling surface is very uneven, you may want to attach a piece of gasket to the open end of the flow box to make a tighter seal - The Energy Conservatory has gasket available.
- Now turn on the Duct Blaster fan and slowly adjust the fan speed until the pressure on **Channel A** (the pressure difference between the flow box and the room) equals zero. Once adjusted in this way, determine the flow through the Duct Blaster fan by measuring the fan pressure on **Channel B** and using the flow table, or by using the digital pressure gauge's fan flow feature.
- The Duct Blaster fan flow at this point is your estimate of air flow through the return register (or exhaust fan) tested.

Note: The Energy Conservatory manufactures an Exhaust Fan Flow Meter which will measure exhaust fan flow rates up to 120 cfm with an accuracy of 10%.

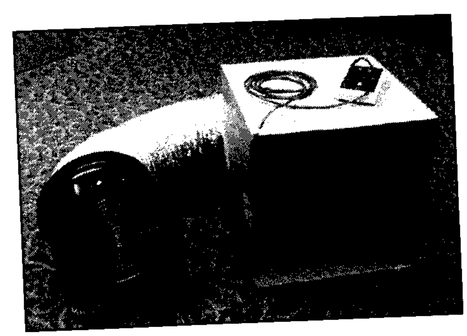
13.3 Measuring Supply Register Flows

As in measuring return register flows, you will need to construct a flow measuring box for this method. One easy option is to use a cardboard box, but a hood from a commercial flow capture hood may also work well. The open end of the flow box or hood should have rough dimensions which are at least 2 times the register dimensions, and the depth of the box should be at least the average of the two opening dimensions.

Part 1: Construct a Flow Box and Make Tubing Connections



- Cut a square hole in the back side of cardboard flow box which is approximately one inch smaller than the dimensions of the square transition piece. Tape and seal the square transition piece over the hole you cut in the box.
- Insert the white foam flow conditioner into the round transition piece. Attach the open side of the round transition piece, along with one of the Flow Rings, to the inlet flange of the Duct Blaster fan. Use the Flow Ring which you think will provide the correct flow range. Connect the open end of the flex duct to the square transition piece on the flow box.



- Punch a small hole (1/4") in one of the corners of the open end of the box and insert a piece of tubing into the hole. Connect the other end of the tubing to the **Channel A Input** tap. The **Channel A Reference** tap should be left open to the room where the register or exhaust fan is located.
- Connect a piece of tubing to the brass pressure tap on the Duct Blaster fan housing. Connect the other end of the tubing to the **Channel B Input** tap.
- The **Channel B Reference** tap should be connected to the plastic pressure tap on the round transition piece using an additional piece of tubing.

Part 2: Install Flow Box and Zero Out the Box Pressure

- Turn on the air handler fan and place the flow box tightly over the supply register. If the wall or ceiling surface is very uneven, you may want to attach a piece of gasket to the open end of the flow box to make a tighter seal - The Energy Conservatory has gasket available.
- Make sure that flex duct is stretched relatively straight (for about 4 feet) where the flex duct is connected to the Duct Blaster fan.
- Now turn on the Duct Blaster fan and slowly adjust the fan speed until the pressure on **Channel A** (the pressure difference between the flow box and the room) equals zero. Once adjusted in this way, determine the flow through the Duct Blaster fan by measuring the fan pressure on **Channel B** and using the flow table, or by using the digital gauge's fan flow feature.
- The Duct Blaster fan flow at this point is your estimate of air flow through the supply register tested.